MICROPHONE SYSTEM FOR EXTREMELY LOW SOUND LEVELS*

by

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ABSTRACT
This article shows how the thermal noise of microphone cartridges, caused by Brownian movements of the diaphragm, can be minimized, and how low inherent noise levels of preamplifiers are obtainable by optimization and the use of modern components.
In an experimental system, third octave and A-weighted noise levels have been reduced by 16 dB relative to conventional systems. This analysis has resulted in the development of a new low noise Condenser Microphone Type 4179 and a matching low noise Preamplifier Type 2660

SOMMAIRE
Cet article montre comment le bruit thermique d'un cause par le mouvement brownien du diaphragme peut être minimise, et comment un faible niveau de bruit interne est obtenu pour le préamplificateur grâce a un choix et a une utilisation appropries de composants modernes.
Un système expérimental a permis de réduire le niveau de bruit en tiers d'octave et pondéré A de 16 dB par rapport aux systèmes classiques; et cette analyse a entraîne le développement d'un nouveau microphone a condensateur Type 4179 avec le Préamplificateur a faible bruit correspondant Type 2660.

ZUSAMMENFASSUNG
Der Artikel zeigt auf, wie das thermisch Rauchen von Mirkonfonkapsein, das durch Brown'sche Bewegungen der Mikrofonmebran verurschacht wird, auf ein Minimum reduziert werden kann und wie sich niedriges Vorverstärker-Eigenrouschen durch optimale Auslegun und die Anwendung modernster Elektronik erreichen läßt.
Versuch haben gezeigt, daß sich A-bewerteteund Terband-Rauschpegel um 16 dB gegenüber herkömmlichen Systemen reduzieren lassen. Diese Ergebnisse haben zur Enwicklung des neuen Kondensatormikrofons 4179 und des speziell auf diese Mikronfonkapsel abgestimmten Vorverstärkers 2660 geführt.

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Introduction

In some application fields, for example, hearing research, there is a need to measure very low sound pressure levels, in the order of –10 dB re. 20 μPa in third octave bands or lower.

The lowest noise level microphone systems existing today, have typical inherent noise levels of 10 to 15 dB(A) or –5 to 5 dB in the third octaves between 20 Hz and 20 kHz. The noise spectrum of such a system is shown in Fig. 1, curve A.

Since the lowest sound levels of interest cannot be measured by such systems directly, use must be made of advanced signal processing and time consuming procedures during which the experimental conditions may change. To overcome these difficulties, experiments have been carried out to reduce the inherent noise form the internal sources of the microphone systems. These noise sources are partly in the microphone cartridge and partly in the preamplifier. While the cartridge noise contributes to the spectrum A it has been eliminated in spectrum B in Fig. 1, which shows the preamplifier noise only. For the measurement of spectrum B, the cartridge was substituted by an equivalent capacitor.

As can be seen, a significant noise reduction requires minimization of cartridge noise as well as preamplifier noise.

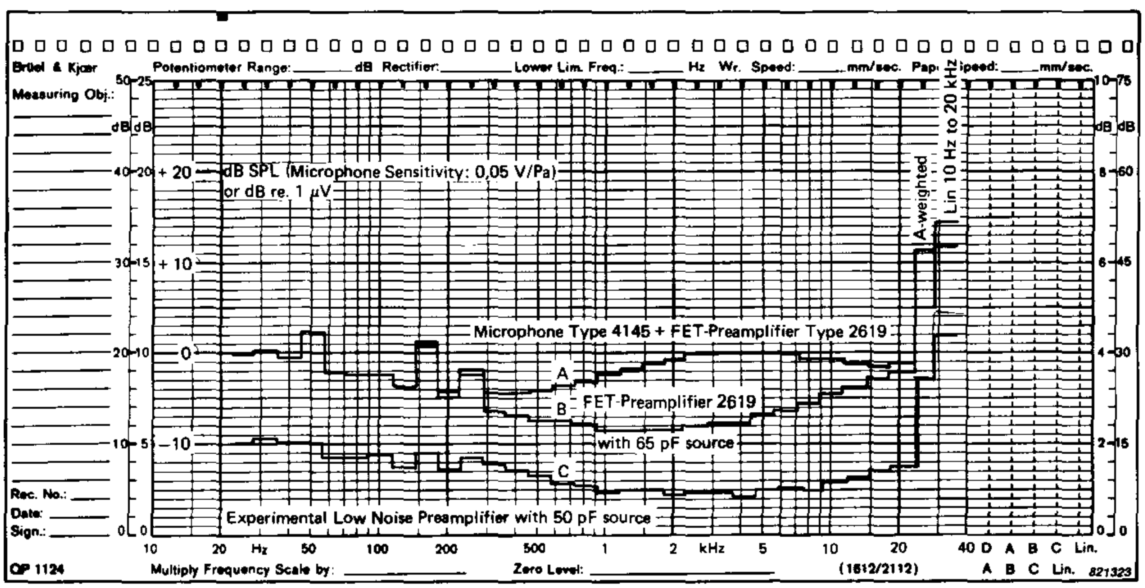

Fig. 1. Third octave analysis of Preamplifier output Noise Voltages

Experimental Low Noise Preamplifier

During the last 10 – 15 years the inherent noise of preamplifiers has been significantly reduced. This is mainly due to the Field Effect Transistor which has replaced the vacuum tube. The dominating noise sources of preamplifiers are described in the literature and shall not be discussed in this paper.

However, by appropriate component selection and careful optimization of the circuit, it has been possible to make experimental preamplifiers, having a 6 – 10 dB lower noise level than corresponding preamplifiers which are available today. With a source capacitance of 50 pF they have typically an A-weighted noise level of 0,7 μV and 1,2 μV for flat weighting from 20 Hz to 20 kHz; the noise spectrum of such an experimental preamplifier is shown in Fig. 1, curve C.

The noise has been reduced to a level which corresponds to the noise of the input stage of modern measuring amplifiers. A low noise voltage amplifier has therefore been combined with the preamplifier to raise its output level by 20 dB, which thus eliminates the influence of the measuring amplifier noise. Extra filtration of the supply voltages has been necessary to minimize hum components in the noise.

Noise sources of Condenser Microphone Cartridges

Analysis of transducer characteristics are often simplified by use of equivalent electrical networks. This is also relevant in connection with analysis of inherent noise in microphone cartridges. A useful condenser microphone model is shown in Fig.2. In electrical as well as acoustical circuits Thermal Noise is produced by resistances or damping mechanisms. The noise pressure produced by an acoustical resistance is determined by the following formula:

$$p_n^{\ 2} = \int_{f_1}^{f_2} 4 \cdot K \cdot T \cdot R_a \cdot df$$

where

$P_n^{\ 2}$ = mean value of squared pressure
K = Boltzmann’s constant
T = absolute temperature
R_a = acoustical resistance
f = frequency

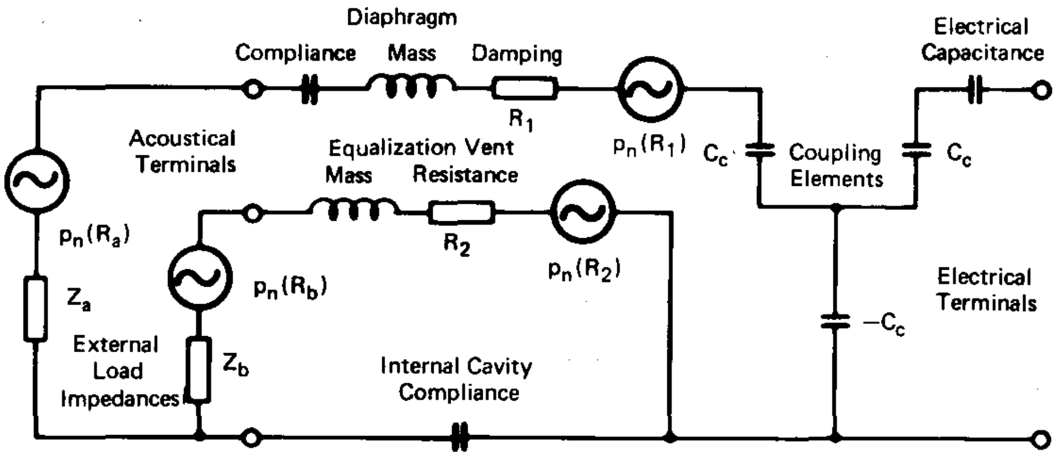

Fig.2 Model of Condenser Microphone Cartridge

Inside condenser microphones there will normally be two such sources. One source belongs to the damping mechanism behind the diaphragm (R_1) and the other one to the resistance of the pressure equalisation vent (R_2).

The impedance loading the diaphragm on its outside (Z_a) has a real part (R_a) which also produces thermal noise. In principle there is a corresponding impedance (Z_b) and resistance (R_b) connected to the outside opening of the equalization vent.

In the equivalent circuit the internal noise pressure generators can be treated as if they were connected to the respective acoustical input terminals. To determine the contribution of each noise generator to the overall cartridge noise, the spectrum of each generator should be multiplied by the transfer function between the respective acoustical input terminals and the electrical output terminals.

Since the typical resistance values of Type 4145 are known, their noise can be calculated. The two transfer function from the acoustical inputs to the electrical output are also known; from the diaphragm terminals it is practically equal to the pressure response, as the outside load on the diaphragm, Z_a is small compared with the acoustical impedance of the diaphragm and its internal damping. The transfer function from the vent opening decreases by 20 dB/decade from the lower limiting frequency of the cartridge, 1,5 Hz to about 1000 Hz where it starts rolling off at a higher rate.

From the above it can be shown the most significant noise source in the Type 4145 is R_1, the diaphragm damping. At frequencies below 30 Hz the vent resistance, R_2 is the most significant noise source.

Experimental Low Noise Microphone Cartridge
Since the most serious cartridge noise in Type 4145 and other existing microphones is produced by the diaphragm damping resistance, R_1, experiments have been carried out to minimize this effect, resulting in the development of 1" cartridges having a resistance 40 time lower than that of Type 4145

As it has not been practically possible to reduce the diaphragm mass and stiffness proportionally, the frequency response of the microphone cartridges changes significantly; a peak appears at the diaphragm resonance (8 kHz). However, an electrical network has been developed which compensates for the microphone response so that a flat response is obtained for cartridge and network up to 13 kHz within 1 dB, see Fig.3.

The sensitivity of the cartridges is increased by 6 dB compared to Type 4145; i.e. –20 dB re 1V per *Pa*.

The sensitivity increase minimized the influence of the preamplifier noise correspondingly; also the compensation network which is combined with the preamplifier contributes to the noise reduction.

The damping resistance, R_1, of the low noise microphone is typically $1{,}25 \cdot 10^6$ Ns/m^5. Its noise pressure ($1{,}43 \cdot 10^{-7}$ Pa/√Hz or –43 dB SPL for 1 Hz bw.) is 16 dB lower than for R_1 of Type 4145. The output voltage noise spectrum is also 16 dB lower, as the transfer function of the

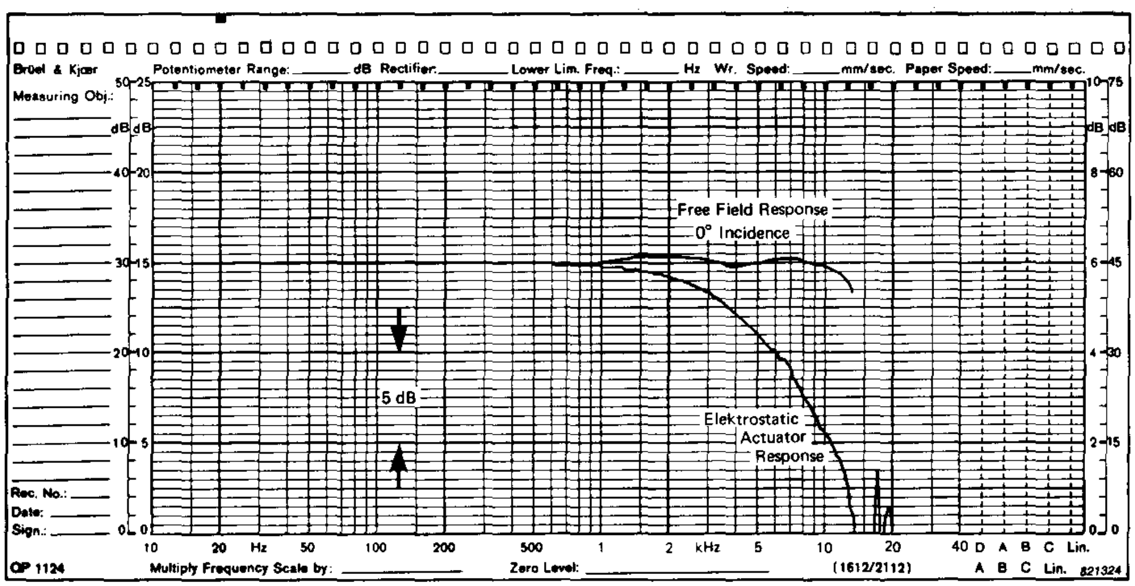

Fig. 3. Frequency Response of Experimental Low Noise Microphone System

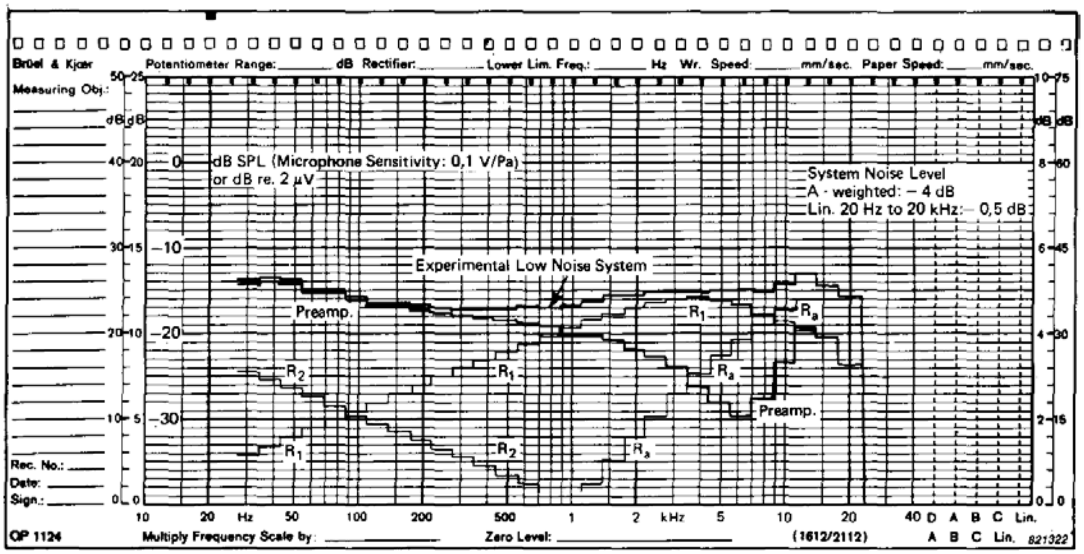

Fig. 4. Third octave analyses of the noise produced by the Experimental Low Noise Microphone System and of the individual elements

experimental cartridge with compensating network is the same as that of the Type 4145, see the third octave spectrum in Fig.4.

Because of the significant cartridge noise reduction the real part of the external load impedance, R_a has become a dominating noise source at higher frequencies, see spectrum in Fig.4. At 10 kHz R_a exceeds the internal diaphragm damping resistance, R_1.

$$R_a = \frac{\rho \cdot f^2 \cdot \pi}{c} \cdot K_r^2;$$

$$R_a[10kHz] = 1{,}5 \cdot 10^6\ Ns/m^5$$

ρ = density of the air;
f = frequency;
c = speed of sound;
K_r = ratio between random and pressure response.

The noise produced by the vent resistance, R_2 which is typically $6 \cdot 10^9$ Ns/m^5 is also shown in Fig.4. Due to the transfer response from the vent terminals, this noise will contribute to the output noise at low frequencies. However, it does not play any practical role, as the preamplifier noise is dominant in that frequency range.

The noise contribution of the external vent resistance, R_b, is very low and can be neglected.

The acoustical noise spectra have all been calculated, while the preamplifier noise spectrum which is also shown in the figure has been measured.

The noise source analysis explains clearly the measured total noise spectrum of the system.

The A-weighted levels of the preamplifier, the internal damping, R_1, and the external load resistance, Ra are –10 dB, -7 dB and –11 dB respectively resulting in an overall level of –4 dB(A).

Conclusion

An experimental one inch microphone system with a flat frequency response up to 13 kHz has been developed; a system which is able to detect extremely low sound pressure level – the inherent A-weighted noise of the system is –4 dB or about 15 dB lower than the noise of any corresponding systems.

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